New data on the structure and hydrocarbon prospects of the Ukrainian Carpathians and their foreland

Ya. V. Sovchik † & *M. A. Vul*

UkrDGRI, Mitskevich sq. 8,
290601 Lliv, Ukraine

ABSTRACT

In the West-Ukraine Carpathian and Volyn-Podolia hydrocarbon provinces 81 oil and gas fields have been discovered. These conatin ultimate recoverable reserves of some $1.2 \cdot 10^9$ bbls of oil and condensate and 15.5 TCF gas. The majority of these fields are located in the external parts of the Carpathians fold and thrust belt and in its adjacent foreland basin. Drilling of deep and superdeep wells resulted in the discovery of 7 oil accumulations in the depth range of 4-6 km.

The nappes of the Ukrainian Carpathians were thrusted during Oligocene and Miocene times over the European foreland platform over a distance of at least 35 km and possibly as much as 75 km. The prospectivity of the sub-thrust autochthonous series is highlighted by the Lopushnya oil field in the Bukovina part of the Carpathians, one field in Romania, 11 fields in Poland and 19 fields in Slovakia. These accumulations, which are partly sealed by the flysch nappes, produce from a variety of reservoirs that were charged with hydrocarbons generated from Paleogene and possibly also Mesozoic source-rocks. The Ukrainian autochthonous sub-thrust play holds the potential for further important hydrocarbon discoveries in structures associated with down-faulting of the foreland crust.

Gas accumulations occurring in the Carpathian foredeep, the Biliche-Volitsa zone, and in the frontal Carpathian structures of the Sambor unit are charged by biogenic gas. In the allochthonous Carpathian flysch, Early Cretaceous and Paleogene sands involved in the Borislav-Pokut, Scybia and Silesian nappes are the principal objectives, as indicated by the occurrence of a number of oil and oil-and-gas fields which are charged by hydrocarbons generated from Paleogene and possibly Early Cretaceous source-rocks. Pressure data and formation water salinities indicate that shales associated with the base of major nappe units act as seals. Intra-formational seals provide for stacked hydrocarbon accumulations in dip-closed anticlinal structures beneath the cover of higher nappes. Subthrust allochthonous and parautochthonous anticlinal roll-over structures hold a considerable potential for future discoveries, particularly if existing reflection seismic resolution problems can be solved.

Sovchik, Ya. V. & Vul, M. A., 1996. — New data on the structure and hydrocarbon prospects of the Ukrainian Carpathians and their foreland. *In*: Ziegler, P. A. & Horváth, F. (eds), Peri-Tethys Memoir 2: Structure and Prospects of Alpine Basins and Forelands. *Mém. Mus. natn. Hist. nat.*, **170**: 391-401. Paris ISBN: 2-85653-507-0.

INTRODUCTION

The West-Ukrainian hydrocarbon province covers an area of some 44000 km^2 and includes the Carpathian fold belt and its Volyn-Podolia foreland. As oil extraction started in this area already around 1771, it is one of the oldest hydrocarbon provinces of the world. In 1909 the Borislav field was discovered from which subsequently 1.92 million tons ($14.2 \cdot 10^6$ bbls) of oil were produced. In 1924 the first gas field (Dashava) was discovered. After a period of little activity, modern exploration intensified in the 1950's after the discovery of the Dolina and Bitkiv oil fields. By now over 90 hydrocarbon fields have been discovered. At present 31 oil, 7 oil-and-gas, 6 gas-condensate and 37 gas fields are in production. Oil production peaked in 1967 at a level of $2.86 \cdot 10^6$ t/year ($21 \cdot 106$ bbls) whereas gas production peaked in 1969 at the level of $12.57 \cdot 10^9$ m^3/year (470 Bcf). Ultimate recoverable reserves in established accumulations amount to some $163.3 \cdot 10^6$ t ($1.2 \cdot 10^9$ bbls) of oil and condensate and $415 \cdot 10^9$ m^3 (15. 5 TCF) of free and associated gas. By spring 1994 cumulative production amounted to $104 \cdot 10^6$ t ($770 \cdot 10^6$ bbls) of oil and condensate and $277 \cdot 10^9$ m3 (10.3 TCF) of gas.

The Carpathian part of the West-Ukrainian oil and gas province is limited to to the northeast by the Bilche-Volitsa zone, corresponding to the Carpathian foredeep basin, and to the west by the Neogene Transcarpathian Depression. The Carpathian thrust- and fold-belt, involving mainly Cretaceous and Cenozoic flysch series, has been subdivided, according to nappe correlations, into an outer Sambor unit, which borders the Bilche-Volitsa zone, and the progressively more internal Borislav-Pokut, Skiba, Silesian and Dukla-Chernogora and Magura units (Fig. 1) (see also Bessereau et al., this volume). To date 38 gas accumulations have been established in the Biliche-Volitsa and the Sambor zones whereas 36 oil and oil-and-gas accumulations were found in the Borislav-Pokut zone. In the internal zones of the Carpathians so far only 2 oil accumulations were found.

The Transcarpathian Depression, which contains up to 2000 m of Neogene clastic sediments, halites and volcanic rocks, is an extensional basin which developed on top of the inner Carpathian nappes; its structure is complicated by the diapirism of Miocene salts. This basin hosts four gas accumulations in Neogene sands.

The Carpathian foreland is occupied by the Volyn-Podolia platform. Its eastern parts are underlain by Precambrian basement which is covered by a westwards expanding wedge of Riphean to Carboniferous sediment, attaining maximum thicknesses of some 7000 m, and a relatively thin veneer of Mesozoic and Cenozoic series. In contrast, the western parts of this platform are floored by folded Palaeozoic sediment which were deformed during the Caledonian and Variscan orogenies; these are covered by up to 2000 m of Mesozoic and Cenozoic sediments. The boundary between these two basement provinces corresponds to the Tornquist-Teisseyre line, a major tectonic lineament which was reactivated time and again during the Mesozoic evolution of the Carpathian geosynclinal system and its Alpine destruction.

The Volyn-Podolia platform is characterized at top-Mesozoic level by a relatively shallow, gently southwestward dipping monocline that shows a low level of structuration. Beneath the Carpathian thrust front, this surface drops down abruptly to depths of 3 to 9 km along a system of major normal faults, such as the Krakovets fault. Based on geophysical data, the foreland crust extends some 75 km beneath the Carpathian edifice of stacked nappes (Fig. 3). Devonian, Late Jurassic and Cenomanian carbonates and Early Cretaceous sands of the Volyn-Podolia platform and its extension beneath the Carpathian thrust and fold belt host a number of oil accumulations.

At present the West-Ukrainian hydrocarbon province includes 38 fields which produce from reservoirs occurring within the Cenozoic, Cretaceous, Jurassic and Devonian strata of the Carpathian foreland and the Carpathian sub-thrust autochthonous sequences, and 36 fields which produce from Cretaceous and Cenozoic reservoirs involved in the folded and thrusted structures of the Carpathians. Two oil, one oil-and-gas and three gas fields each have initial technically recoverable reserves in excess of $30 \cdot 10^6$ t ($200 \cdot 10^6$ bbls) oil and oil-equivalents. One oil and seven gas fields are in the $10\text{-}30 \cdot 10^6$ t ($75\text{-}200 \cdot 10^6$ bbls) class;

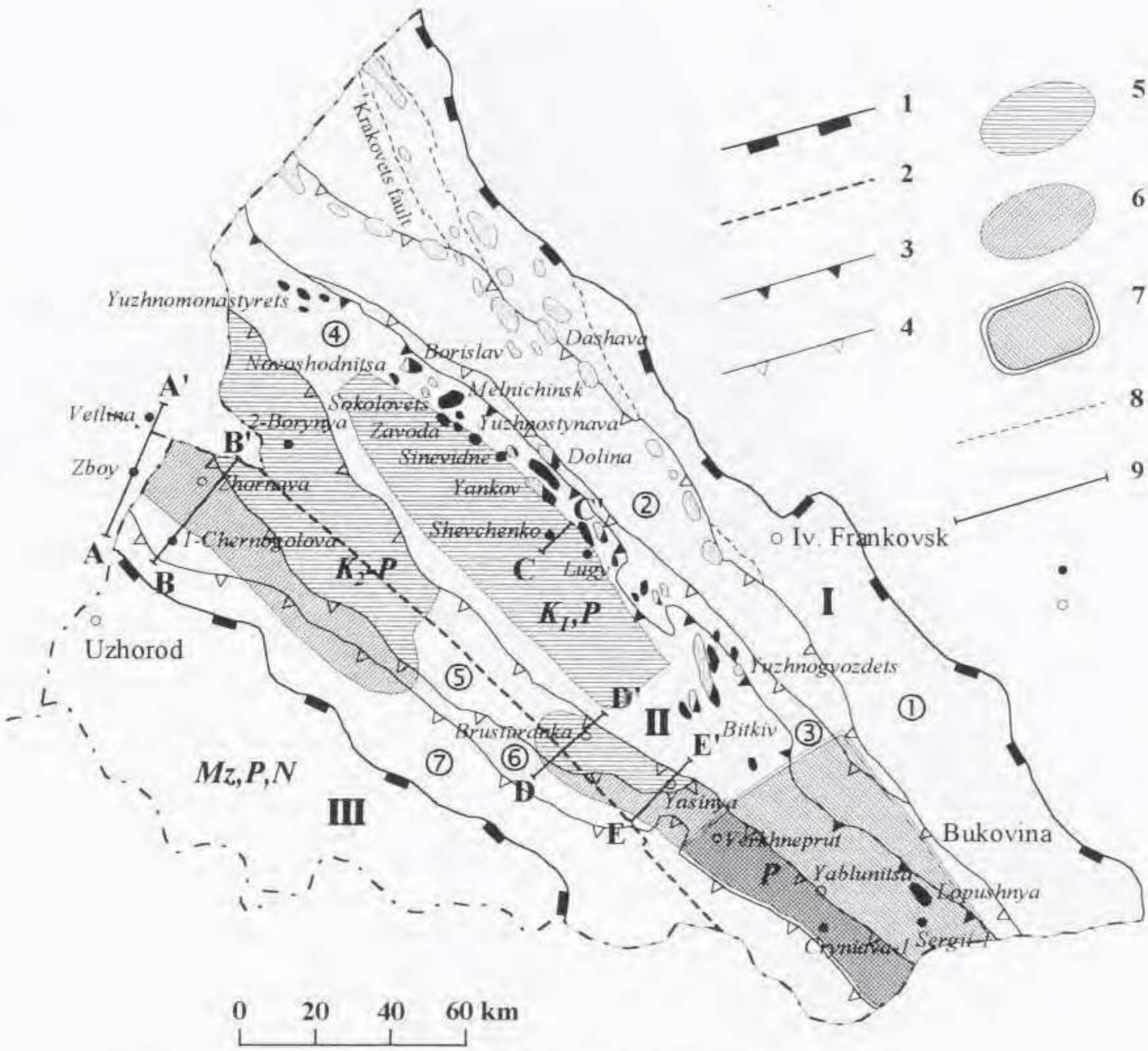

FIG. 1. Tectonic units of the West-Ukrainian Carpathians and oil and gas fields. oil fields: black, gas: fields dotted

I: Carpathian foredeep - 1. undeformed Biliche-Volitsa zone, 2. Deformed Sambor zone, 3. Borislav-Pokut nappe.

II: Stacked Carpathian nappes - 4. Scybia nappe, 5. Silesian nappe, 6. Dukla-Chernogora nappe, 7. unprospective Magura nappe.

III Transcarpathian Basin

Line symbols: 1. Basin outlines, 2. approximate western limit of autochthonous foreland crust, 3. outcropping boundaries of Carpathian nappes, 4. subsurface nappe fronts, 5. prospective area in exposed nappes with age of objective series, 6. prospective area in sub-thrust allochthonous and parautochthonous units with age of objective series, 7. prospective area in sub-thrust autochthon, 8. regional normal faults affecting foreland and autochthon, 9. Lines A-A', B-B', C-C', D-D': location of cross-sections given in Fig. 4

Well symbols: black- drilled wells; open- proposed well locations

Oil fields: black; gas fields: dotted

67 fields (34 oil, 33 gas) each have reserves below $10 \cdot 10^6$ t ($75 \cdot 10^6$ bbls) oil and oil equivalents.

In the past exploration activity was largely limited by the drilling capacity. Whereas up to 1965 no wells were drilled to depths of 4000 m, such wells made up 10% and 38% of all wells drilled during the periods of 1966 to 1970 and 1971 to 1975, respectively. In the 1970's 13 wells were drilled in the Carpathian foredeep and within the Carpathians to depths of more than 6000 m. Amongst these, the wells Sinevidne and Shevchenko reached total depths of 7001 and 7520 m, respectively. Although deep wells have yielded important new structural and stratigraphic information, only a fraction of the expected reserve potential of the deep plays has so far been proven up.

For the entire area recoverable reserves in established accumulations (production, proven and probable reserves), amounting to some $400 \cdot 10^6$ t ($3 \cdot 10^9$ bbls) of oil and oil equivalents, account for approximately 43% of its expected ultimate reserve potential. In the Carpathian foredeep some 55% of the ultimate potential reserves have so far been proven up. Although plays at the depth interval of 4-7 km are thought to hold a considerable potential (close to 30% of the total regional potential reserves), large areas are still poorly explored.

VOLYN-PODOLIA PLATFORM AND CARPATHIAN AUTOCHTHON

The eastern Volyn-Podolia platform forms part of the Precambrian East-European Craton, the western limit of which is defined by the Tornquist-Teisseyre zone that coincides with the Palaeozoic Caledonian and Variscan deformation fronts. This northwest-southeast trending line extends from Poland into the Ukrainian Carpathian foreland where it forms the western limit of the deep Lublin-Lviv Palaeozoic basin. Southeastwards the Tornquist line projects beneath the Bilche-Volitsa and Sambor zones of the central and southern Ukrainian Carpathians.

The the Precambrian basement of the Volyn-Podolia Platform dips gently westwards and reaches depths of some 9 km to the northwest of Lviv. It is covered by up to 800 m of Riphean continental clastics and a westwards expanding wedge of Cambrian, Ordovician and Silurian sands, shales and carbonates, attaining maximum thicknesses of some 4000 m near the Late Caledonian deformation front which was established by boreholes to the west of Lviv. After a short break at the transition from the Silurian to the Devonian, sedimentation resumed with the accumulation of Early Devonian red beds which are overlain by Middle and Late Devonian carbonates, Early Carboniferous shales and carbonates and a Late Carboniferous paralic, partly coal bearing sequence which is exploited in the Lublin-Lviv coal basin. Also the Late Palaeozoic sediments form a westward expanding wedge which attains maximum thicknesses of some 3000 m in the area of Lviv, to the west of which they were deeply truncated as a consequence of their Variscan deformation (Rizun and Sen'kovskiy, 1973; Wjalow and Medwedew, 1977).

During Permian and Early Mesozoic times, the Volyn-Podolia Platform and its extension beneath the Carpathian nappes was an area nondeposition and erosion. In contrast, contemporaneous rifting activity resulted in and the subsidence of the Polish Trough and the opening of the oceanic Magura basin in the internal Carpathian domain (Birkenmajer, 1986; Kovac et al., 1993). In the area of the Volyn-Podolia Platform sedimentation resumed during the Middle and Late Jurassic, initially with the deposition of a deltaic series followed by the establishment of a broad carbonate shelf (Izotova and Popadyuk, this volume). Marine sedimentation persisted until the end of the Cretaceous when the western parts of this shelf were deformed, uplifted and subjected to erosion in conjunction with the inversion of the Polish Trough (Ziegler, 1990; Bessereau et al., this volume). During the Paleogene erosional phase a system of southwesterly trending palaeo-valleys developed. These cut deeply into the Mesozoic and Palaeozoic cover of the Volyn-Podolia Platform (Fig. 2). This Paleogene palaeotopographic relief was inundated during the Eocene and Oligocene in conjunction with the development of the Carpathian foreland basin in which sedimentation persisted until

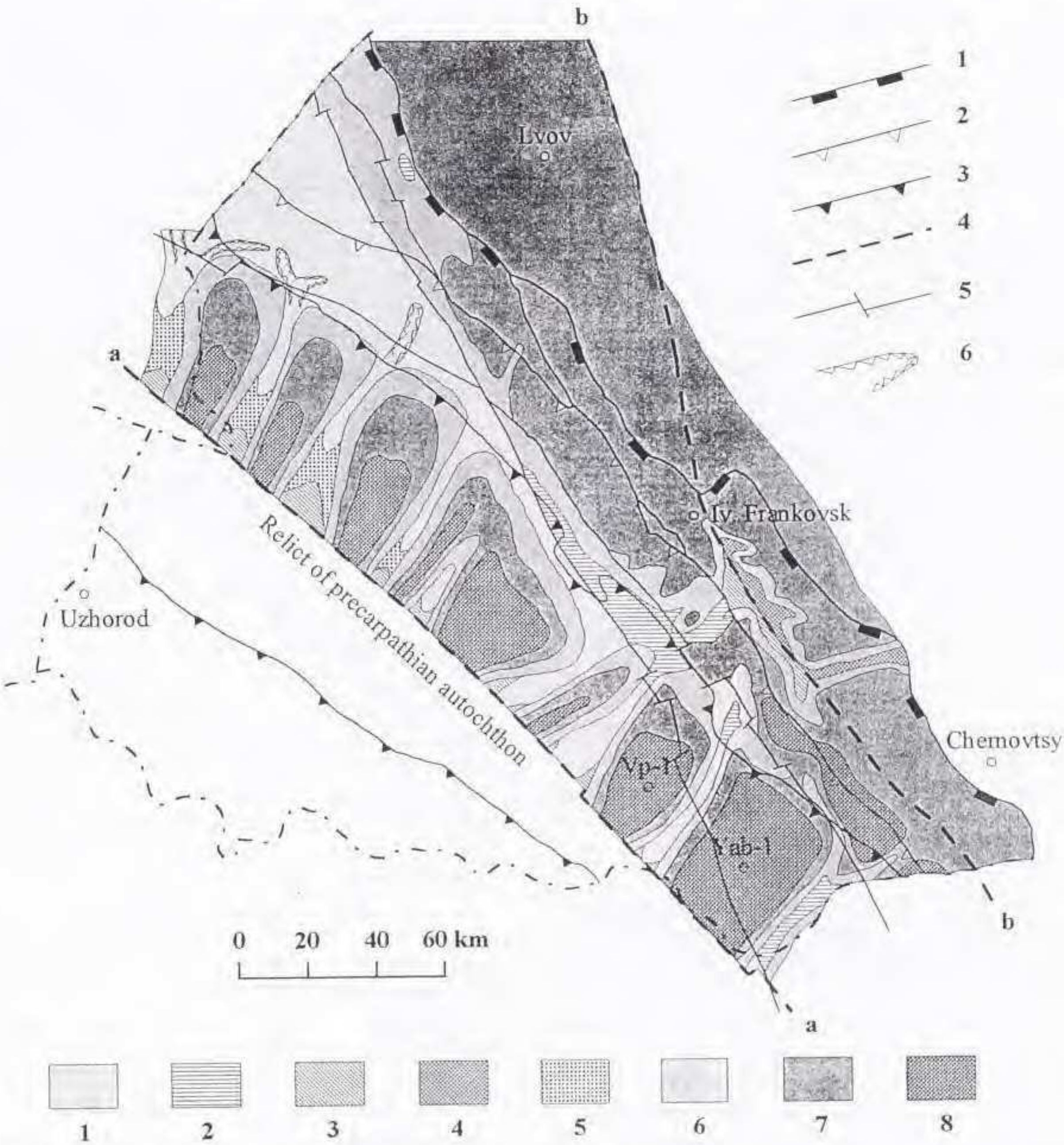

FIG. 2. Tentative subcrop map of pre-Neogene erosional surface of sub-thrust autochthon.
Line symbols: 1. Eastern margin of Biliche-Volitsa zone, 2. Carpathian thrust front (eastern margin of Sambor unit), 3. Eastern margin of Scybia nappe, 4a) Western margin of autochthonous foreland crust, 4b) Tornquist-Teisseyre Line separating Precambrian East-European Platform from Palaeozoic crust of Central Europe, 5. major normal faults affecting autochthon, 6. incised valleys of the pre-Neogene erosional surface
Area symbols (subcropping units): 1. Upper Proterozoic, 2. Cambrian, 3. Ordovician to lowermost Devonian, 4. Early Devonian red beds(Dniester series), 5. Devonian-Carboniferous, 6. Jurassic, 7. Cretaceous, 8. Paleogene
Vp - Verkhneprut, Yab - Yablunitsa proposed stratigraphic tests

Pliocene times. Subsidence of this basin was accompanied by the development of a system of synthetic normal faults amongst which the Krakovets fault, having a throw of up to 3000 m, is the most important one. Emplacement of the Carpathian nappes on the passive margin of the Volyn-Podolia Platform commenced during the late Oligocene and terminated at the end of the Miocene (Ellouz and Roca, 1994).

Major reservoirs established on the Volyn-Podolia Platform and on its southwestward extension beneath the Carpathian nappes are Devonian sands and carbonates, Late Jurassic carbonates and Early Cretaceous, Cenomanian and Paleogene sands (Izotova and Popadyuk, this volume). Potential source-rock are shales of Upper Proterozoic, Cambrian and Silurian age, Early Cretaceous shales and the Oligocene Menilites shales. Plays aimed at Palaeozoic reservoirs and source-rocks are limited to the West by the Tornquist-Teisseyre zone.

HYDROCARBON ACCUMULATIONS AND PROSPECTS IN THE CARPATHIAN AUTOCHTHON AND PARAUTOCHTHON

In view of the above, the reservoir potential of the autochthonous foreland which extends deep under the Carpathian nappes, is restricted to the Late Jurassic carbonates and Early Cretaceous, Cenomanian, Paleogene and Neogene sands. In the Ukraine, 20 oil and gas fields have been established in autochthonous sediments beneath the Carpathian nappes at depths up to 4300 m. An example is the high out-put Lopushnya oil field which produces from stacked Mesozoic and Paleogene reservoirs at depths between 4000 and 4300 m (Izotova and Popadyuk, this volume). The potential of the sub-thrust play is highlighted by the discovery of the Frasyn field in Romania, 19 fields in Slovakia and 11 fields in Poland. These accumulations, which are partly sealed by the flysch nappes and produce from a variety of reservoirs, are charged with hydrocarbons generated from Paleogene and possibly also Mesozoic source-rocks.

In the Ukrainian sub-thrust play, the distribution of Mesozoic reservoirs is controlled by the westward shale-out of the Late Jurassic carbonates (Izotova and Popadyuk, this volume) and by the Paleogene erosional unconformity which truncates all Mesozoic objective horizons. However, this unconformity can also contribute towards reservoir development by means of karstification of Jurassic carbonates. Fig. 2 presents a tentative Neogene subcrop map which is based on well and reflection seismic data. Beneath the Carpathian nappes this erosional surface is located a depths ranging from 2 to 9 km, as shown in Fig. 3.

The sub-thrust autochthonous sedimentary sequence includes, apart from several reservoir horizons, Lower Cretaceous and Neogene seals. In addition, sheared shales at the base of the flysch nappes have a sealing capacity as evident, for instance, in the stratigraphic Grinyava-1 well. Hydrocarbon supply to autochthonous sub-thrust prospects does not appear to be a problem and is apparently provided by the Oligocene Menilites shales and possibly also by Early Cretaceous shales and Late Jurassic sediments developed in an off-reef facies (see Bessereau et al., this volume). The occurrence of oil accumulations down to depths of 5300 m highlights the potential of this play and raises doubts whether over-maturity of source rocks is a limiting factor.

In the deeper parts of the Carpathian sub-thrust play, reflection-seismic definition of drillable structures at the level of the autochthonous and parautochthonous series has so far been difficult. However, a number of oil accumulations have been discovered at depths of 4300 to 5800 m (Juzhnomonastyrets, Novoskhodnitsa, Sokolovets, Zavada, Melnichinsk, Yuzhnostynava, Jankov and Juznogvozdets fields). At present a number of structural leads are recognized which require detailing and the application of the most modern reflection-seismic techniques. Zones of interest are in the southeast the North Bukovina transverse uplift (5-6 km depth) and in the northwest the area covered by the Sambor nappe (Fig. 3). Similarly prospects may be associated with the platform marginal faults, including roll-over structures in down-thrown hanging wall blocks (Izotova and Popadyuk, this volume).

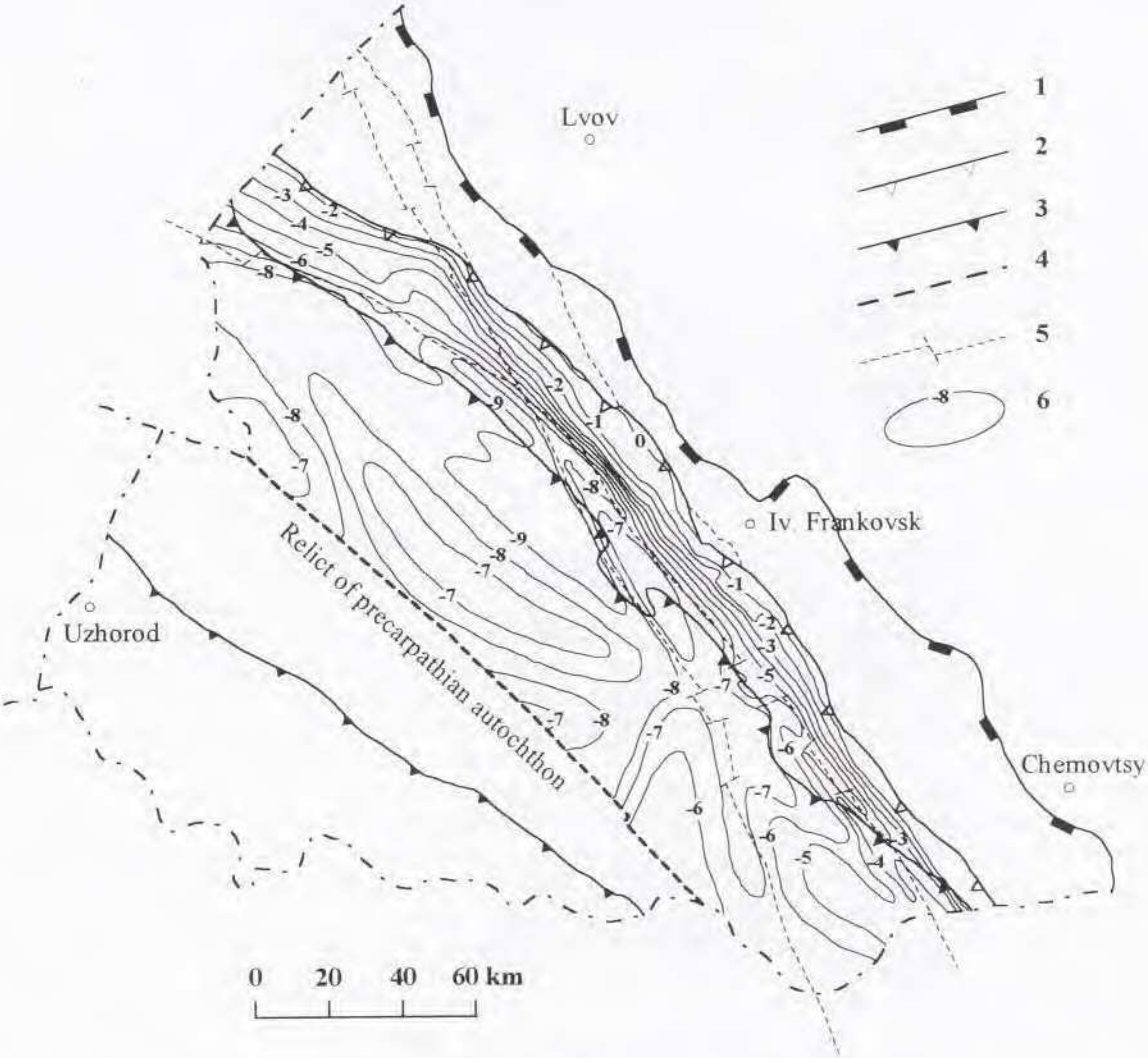

FIG. 3. Structural map of the pre-Neogene unconformity of sub-thrust autochthon and foreland.
Line symbols: 1. Eastern margin of Biliche-Volitsa zone, 2. Carpathian thrust front (eastern margin of Sambor unit), 3. Eastern margin of Scybia nappe, 4. Western margin of autochthonous foreland crust, 5. major normal faults affecting autochthon, 6. Depth contours of Paleogene unconformity in km.

The autochthonous sub-thrust play of the Carpathians still holds considerable potential and, despite certain seismic resolution problems and great objective depths, should not be unduly downgraded.

CARPATHIAN NAPPES

The Carpathian nappes involve a continuous sequence of Early Cretaceous to Miocene shales and flysch-type sandstones which attain thicknesses of 5 to 8 km. These clastics accumulated in deeper water basins that were floored by extended continental crust and possibly partly by oceanic crust. Sands were shed into these basin from the rising Carpathian orogen and to a lesser degree from the Volyn-Podolia shelf. A tentative palinspastic restoration of the Ukrainian Carpathians suggests an overall shortening of some 230 km since the Cretaceous; of this, about 180 km was achieved during the Late Oligocene to Pliocene folding and thrusting of the outer Carpathian flysch units (Ellouz and Roca, 1994).

Reflection-seismic data and results of deep wells, such as Sergii-1 (drilled 15 km to the West of the Carpathian thrust front, bottomed in autochthonous Badenian 5023 m), show that the Carpathian nappes were thrusted a minimum of 35 km over the autochthonous foreland. However, on reflection-seismic data the foreland crust can be traced westwards at least as far as the Chernogora nappe which is apparently floored by parautochthonous continental basement; this would imply a nappe transport of up to 75 km. How much of the basement of the Borislav-Pokut, Skiba and Silesian basins was subducted at the leading edge of the parautochthonous block, which underlies the Dukla-Chernogora nappe, is a matter of debate. However, Neogene calcalkaline volcanic activity in the Transcarpathian basin testifies to the subduction of a large amount of crustal material which had underlain these flysch basins (Szabo et al., 1992).

The thickness of the Carpathian nappe stack is adequately constrained by wells and reflection seismic data in the Sambor and Borislav-Pokut zones but is only partially known in the internal Carpathians where it may exceed 8000 m. To this end, plans have been formulated to drill two test wells in the Dukla-Chernogora nappe. The well Verkhneprut is scheduled for a total depth of 8000 m. The Yablunitsa test with a planned total depth of 5950 m will be located on a deep seated autochthonous structure (Fig. 1).

The Biliche-Volitsa zone, which corresponds to the little deformed Carpathian foredeep, and the adjacent frontal Sambor zone of the Carpathian thrust belt are well explored and contain 42 gas accumulation and one oil-and-gas field. Their reservoirs are formed by Late Jurassic carbonates and Upper Cretaceous and Neogene sandstones. Similar to the adjacent Polish fields, the gas is of biogenic origin. The oil is most likely related to Palaeozoic source-rocks.

On the other hand, exploration activity aimed at evaluating the hydrocarbon potential of the main body of the Carpathian allochthon was in the past at a low level and amounted to only 5% of the total exploration effort.

Drilling activity was mainly directed towards the assessment of the hydrocarbon potential of the Early Cretaceous an Paleogene series of the Scyba nappe and of the Paleogene series of the Silesian zone. Most wells were located on surface structures. Results show that anticlinal structures, which rely for closure on thrust faults, are wet whereas thrusted anticlines with a 4-way dip closure contain hydrocarbons, sometimes in stacked accumulations sealed by shales intercalated with the reservoir sands. Although regional seals are provided by the Oligocene Menilites shales, the high sand/shale ratio of the objective section probably plays an important role in the apparently limited sealing capacity of individual thrust faults (Sovchik, 1979; Sovchik and Krupsky, 1988).

On the other hand, the deep well Gryniava-1, which drilled through the base of the Chernogora nappe 7 km to the west of its erosional edge, tested from the Oligocene Krosno flysch of the underlying Silesian nappe under anomalously high formation pressures gas at commercial flow rates. Together with the results of similar exploratory wells, this suggests that sheared shales at the base of major nappes do have a considerable sealing potential. Moreover, under high pressure condi-

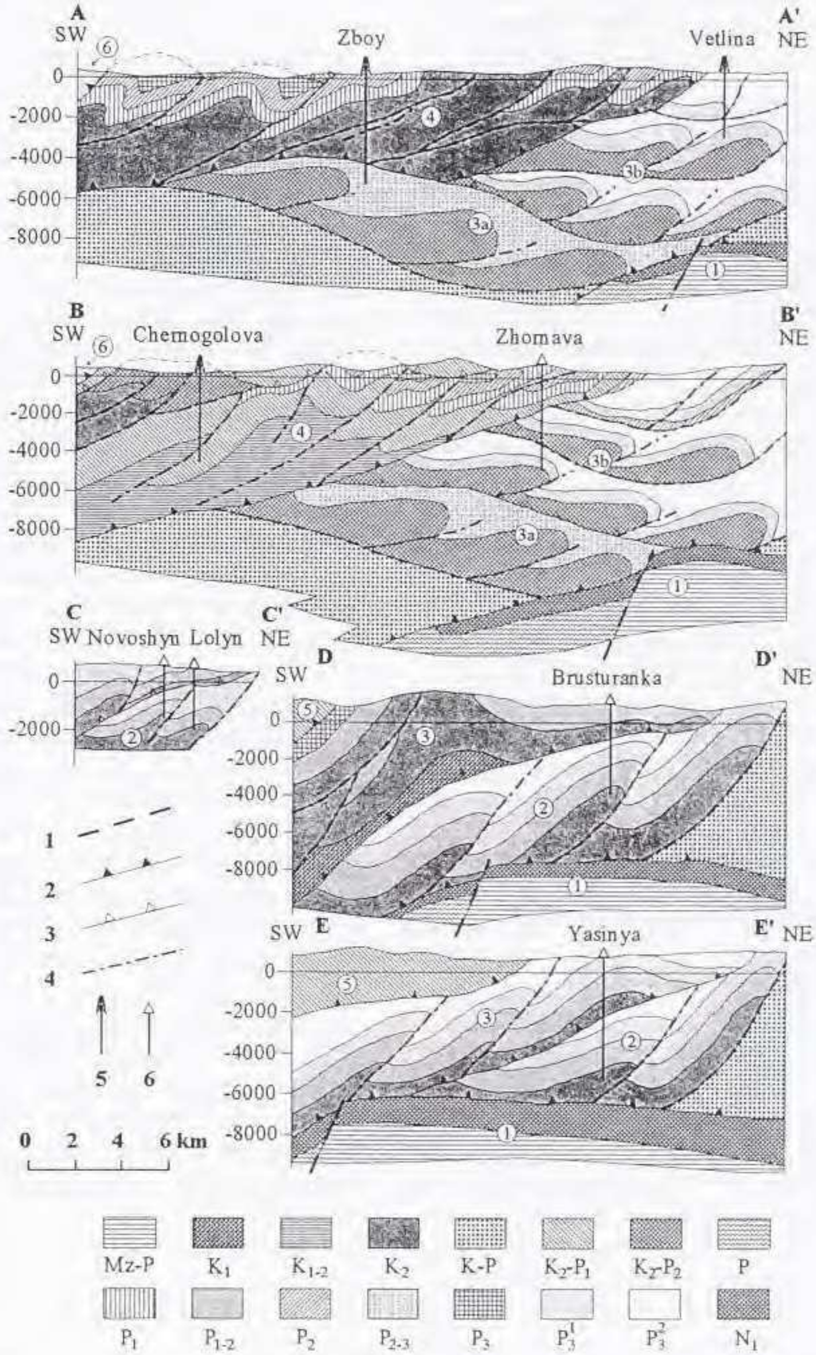

FIG. 4. Structural cross-section, for location see Fig. 1

Tectonic units (numbers in circles): 1. autochthon, 2. Scybia nappe, 3. Silesian nappe (3A Obidov sub-zone, 3B Predukla sub-zone), 4. Dukla nappe, 5. Chernogora nappe, 6. Pokulets nappe

Line symbols: 1. normal faults affecting autochthon, 2. nappe boundaries, 3. boundaries between sub-nappes, 4. thrust faults within nappes

Well symbols: black- drilled wells; open- proposed wells tions, intra-formational shales appear to have a higher sealing potential than under hydrostatic conditions. This notion is in keeping with the results of the Lopushnya field which is partly sealed by the overlying Sambor nappe and partly by intra-formational Mesozoic shales. Supporting evidence for effective hydrodynamic separation between nappes is provided by significant changes in the salinity of formation waters, as seen, for instance, in the wells Borynya-2 and Zboy-1 (Fig. 4a, Durkovic et al., 1980). Whereas nappes exposed at the surface are deeply invaded by meteoric waters, normal salinities are encountered under sub-thrust conditions; as such, this probably contributes towards the preservation of hydrocarbon accumulations under sub-thrust conditions.

Generally it is observed that the degree of organic metamorphism and diagenetic deterioration of reservoirs is lower in the parautochthonous and external nappes than in the overlying, more internal nappes (Khain and Sokolov, 1990). That indeed viable reservoirs occur at considerable depths is illustrated by test results of the well Shevchenkovo-1, which recovered water from Cretaceous sands at depths of 6930-6990 m at the rate of 16 m^3/d, and Lugy-1 which recorded from Cretaceous sands flow rates of water of 12 m^3/d from interval 6180-6260 m and 58 m^3/d from interval 5430-5525 m. In the Borislav-Pokut zone, commercial flow rates of oil (27-1633 b/d) were obtained from Paleogene sands in the following fields: Yuzhnomonastyrets (4945-4962 m), Novoshodnitsa (4365-5050 m), Sokolovets (5704-5796 m), Zavada (4390-5050 m), Melnichinsk (4497-4790 m), Yuzhnostynava (4677-4712 m, Yankov (5183-5292 m) and Yuzhnogvozdets (4080-4386 m).

Surface geological mapping, results of deep wells and reflection-seismic data indicate that the internal nappes are characterized by a considerably greater structural complexity than the more external nappes (Fig. 4). On the other hand, frontal thrust structures are generally steep and rely on fault closure whereas more internal structures are characterized by a lower relief and large anticlinal roll-overs. As structures of this type do not exclusively rely on fault closure, they have a considerably greater potential to contain commercial volumes of hydrocarbons.

Keeping the above developed concepts in mind, future exploration should be aimed at assessing the hydrocarbon potential of those parts of the nappes which are covered by more internal nappes. This applies specifically to the inner parts of the Scybia and Silesian nappes which are covered by the Silesian and the Dukla-Chernogora nappe, respectively. The principal targets are Oligocene Krosno sands involved in role-over anticlinal structures.

This play concept is illustrated by the Brusturanka and Yasinya prospects shown in Figs. 4d and 4e; both of these planned wells are aimed at structures within the Scybia nappe which are covered by the Silesian nappe. However, as definition of the prospective structures is hampered by poor seismic resolution, these wells carry a considerable structural risk. In the southeastern parts of the Carpathians, interesting exploration targets are sub-thrust prospects beneath the Chernogora nappe in which first encouraging results were obtained in well Grinyava-1. Drilling targets are here the Krosno sands of the Silesian and Scyba nappes as well as the Mesozoic and Cenozoic series of the underlying autochthon. Similar prospects may exist beneath the Chernogora-Dukla nappe in the Silesian nappe as illustrated in Figs. 4a and 4b. An example is the Zhornava prospect, located 6.5 km to the southwest of the erosional edge of the Dukla nappe, which aims at evaluating the potential of the Krosno sands involved in a gentle anticlinal structure.

Due to the complex structuration of the internal nappes, reflection-seismic resolution of such sub-thrust prospects is generally poor. However, if seismic resolution can be improved by applying modern technology, such as 3-D surveys, a new cycle of successful exploration may be opened. It is anticipated that future exploration in the Carpathian allochthon will be rewarded with the discovery of a number of small and medium sized hydrocarbon accumulations occurring at a depth range of 4-6 km.

CONCLUSIONS

Although exploration for hydrocarbons in the Ukrainian Carpathians and their immediate foreland can look back on a long and successful history, the application of modern reflection-seismic technologies may open a new cycle of exploration activity. Experience gained during past exploration cycles shows that there is no shortage in hydrocarbon supply to properly sealed traps occurring in the sub-thrust autochthonous and foreland series as well as within the Carpathian allochthon. Both the autochthonous sub-thrust play and prospects within the Scyba, Borislav-Pokut and Silesian nappes are oil-prone.

In the southeastern parts of the Carpathians, the autochthonous substrate with its Mesozoic and Paleogene reservoirs is a of zone of prime interest. Within the Carpathian allochthon, the Paleogene and Early Cretaceous sands of the Scyba and Borislav-Pokut nappes and the Paleogene sands of the Silesian zone are likely to yield additional discoveries.

Acknowledgements- The senior author of this paper, Dr. Ya. Sovchik, whose participation in the 1993 AAPG Conference in Den Haag was sponsored by *Shell Internationale Petroleum Mij. B.V.*, died in April 1994. His great contributions to the understanding of the hydrocarbon habitat of the Ukrainian Carpathians and their foreland are gratefully acknowledged by his colleagues in UkrDGRI. The co-author, who herewith dedicates this paper to his former colleague, extends his thanks to Dr. P.A. Ziegler for critical and constructive comments on a first draught of this paper and for his editorial efforts.

REFERENCES

Birkenmajer, K. (1986), "Stages of structural evolution of the Pieniny Klippen Belt, Carpathians". *Studia Geologica Polonica, Warszawa*, **88**, pp. 7-32.

Durkovic, T., T. Koràb and R. Rudinec (1980), "Hiboky structurny vrt Zboj-1". *Reg. Geol. Zapad. Karpat., Bratislava*, **16**, pp. 76.

Ellouz, N. and E. Roca (1994), Palinspastic reconstruction of the Carpathians and adjacent areas since the Cretaceous. In *Peri-Tethys Platforms* (Edited by Roure, F.). Édition Technip, Paris, pp. 51-78.

Khain, V.E. and B.A. Sokolov (1990), "Formation problems of nappe-upthrust areas in connection with their oil-and-gas-bearingness". Moscow, Nauka, 1, pp. 3-10.

Kovac, M., A. Nagymarosy, J. Sotak and K. Sutovska (1993), "Late Tertiary paleogeography of the West Carpathians". *Tectonophysics*, **226**, pp. 401-515.

Sovchik, Ya.V. (1979), "Materials to paleogeography of the Carpathian Paleogene Basin". *Geol. Mag., Kiev*, **39**, pp. 36-48.

Sovchik, Ya.V. and Yu.Z. Krupsky (1988), Oil-and-gas-bearingness prognosis of Paleogene deposits of the Silesian and Scybian nappes, southeastern part of Ukrainian Carpathians. In *UkrSSR Regional Geology and Oil and Gas Prospecting Directions*. Coll. art., Lvov, UkrNIGRI, pp. 48-56.

Szabo, Cs., Sz. Harangi and L. Csontos (1992), "Review of Neogene and Quaternary volcanism of the Carpathian-Pannonian region". *Tectonophysics*, **208**, pp. 243-256.

Rizun, B.P. and Yu.N. Sen'kovskiy (1973), "Position of the southern boundary of the East-European platform in the Ukraine". *Geotectonics*, **4**, pp. 211-215.

Wjalow, O.S. and A.P. Medwedew (1977), "Die präalpidische Struktur des westlichen Ukraine und Südpolens und die Wechselbeziehung zwischen Tafel- und Geosynklinalgebieten". *Zeitschr. angew. Geologie*, **23**, 10, pp. 517-521.

Ziegler, P.A. (1990), *Geological Atlas of Western and Central Europe. 2nd. Ed.* Shell Internationale Petroleum Mij. B.V., distributed by Geol. Soc. Publishing House, Bath, 223 p.